

Graphical technique lets you optimally bias bipolar-junction-transistor circuits

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Biased an active device, such as a bipolar junction transistor (BJT), requires that you set the dc voltages and currents of the device. To optimize the desired result, you need various bias values. For instance, the input device for a low-noise amplifier

may have its best noise performance at 50 μ A of collector current and a maximum of 5V of collector-to-emitter voltage, whereas later amplifier stages may require 20-mA collector current and 18V collector-to-emitter voltage to generate the necessary ac voltage at the output. When you determine the desired bias conditions, you also need to make sure they are repeatable—within certain limits—to ensure consistent performance.

Biased-technique analysis for BJTs generally progresses in complexity from the fixed-bias method, to the shunt circuit, to the stabilized circuit, (Figures 1a, 1b, and 1d, respectively). Studies do not usually cover the shunt-divider circuit (Figure 1c) and universal (Figure 1e) circuit. However, questions still arise about the bias stability of the shunt bias circuit. It is usable in some noncritical applications, but how inferior is it to the stabilized circuit? Designers are generally taught that the stabilized circuit is the one to use for repeatable biasing.

One way to analyze the stability of the various biasing methods is to use stability factors, which characterize the change in collector current due to changes in the transistor's H_{FE} (current gain), I_{CBO} (collector-to-base leakage current), and V_{BE} (References 1 and 2). Although these factors are useful, comparing bias circuits and bias-resistor values requires tedious calculations. A visual presentation that compares the stability of the various circuits is more useful.

Looking at the equation for I_C in Figure 1b, note that much of the change in I_C is due to the differing voltages developed across R_1 because of the range of H_{FE} . This differ-

You can bias a bipolar junction transistor in several ways. Determining the best method for your application is easy with a graphical technique.

ence leads to a question: If some of the current through R_1 is fixed, would the result be less voltage change across R_1 and hence, less change in I_C ? This thinking leads to the shunt-divider circuit (Figure 1c). Because V_{BE} changes little, R_2 supplies a relatively

fixed component of the current through R_1 , making R_1 a smaller value than it would be without R_2 . The equation for the shunt divider shows that a smaller value of R_1 in the denominator causes less change in I_C due to changes in H_{FE} . However, along with R_C and R_2 , R_1 shows up in the numerator as a multiplying factor for V_{BE} .

You can next look at how strongly each of these factors influences I_C . Because you can derive all the circuits in Figure 1 from the universal circuit (Figure 1e) by making the appropriate resistors either infinite (open circuits) or zero (short circuits), the same universality is possible for the equations. Considering the circuit equations and a range of parameters and bias-resistor values, you can produce graphs in which the Y axis represents the change in I_C .

To make valid comparisons of the circuits, you need a common parameter related to the biasing for the X axis. The ratio of the collector current to the bias current in R_1 works. This ratio is common to the circuits and reflects how stiff the biasing is. To show realistic conditions, the data also includes temperature effects on V_{BE} and H_{FE} for a temperature range of 25 to 75°C and a 3-to-1 spread in H_{FE} .

For comparison purposes, all the circuits use a 10V supply for V_{CC} at a nominal collector current of 1 mA, with H_{FE} of 100 and V_{BE} of 0.60V at 25°C. Calculating resistors for 5V V_{CE} and selecting R_E to develop 1V at the emitter produces the results for the graphical technique. The model for temperature effects of the device is $V_{BE}=0.60-0.002 \times (T(\text{actual}) - 25^\circ\text{C})$, representing the standard 2-mV/°C coefficient for diodes. Calculations from the data sheet of the 2N2222A

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transistor produce an average temperature coefficient for H_{FE} of about $0.58\%/^{\circ}\text{C}$, which you can represent by $H_{FE_Temp} = H_{FE_Max} [1 + (T(\text{actual}) - 25^{\circ}\text{C})0.0058]$. Calculating I_C for a minimum $H_{FE} = 50$ at 25°C and for the maximum $H_{FE} = 150$ at 75°C yields an H_{FE_Temp} of 194 and V_{BE} of 0.50V.

This analysis ignores the effects of I_{CBO} . For the nominal collector current of 1 mA and a maximum temperature of 75°C , the contribution of I_{CBO} to I_C is a few percent, at most, for the fixed-bias and shunt-bias circuits in Figures 1a and 1b and less for the bias circuits of Figures 1c, 1d, and 1e.

Graphical approach shows trade-offs

The results of this analysis appear as a simple visual comparison of the current stability of the various types of bias circuits (Figure 2). Using this figure, you can select the type of bias circuit and the bias ratios for the necessary stability.

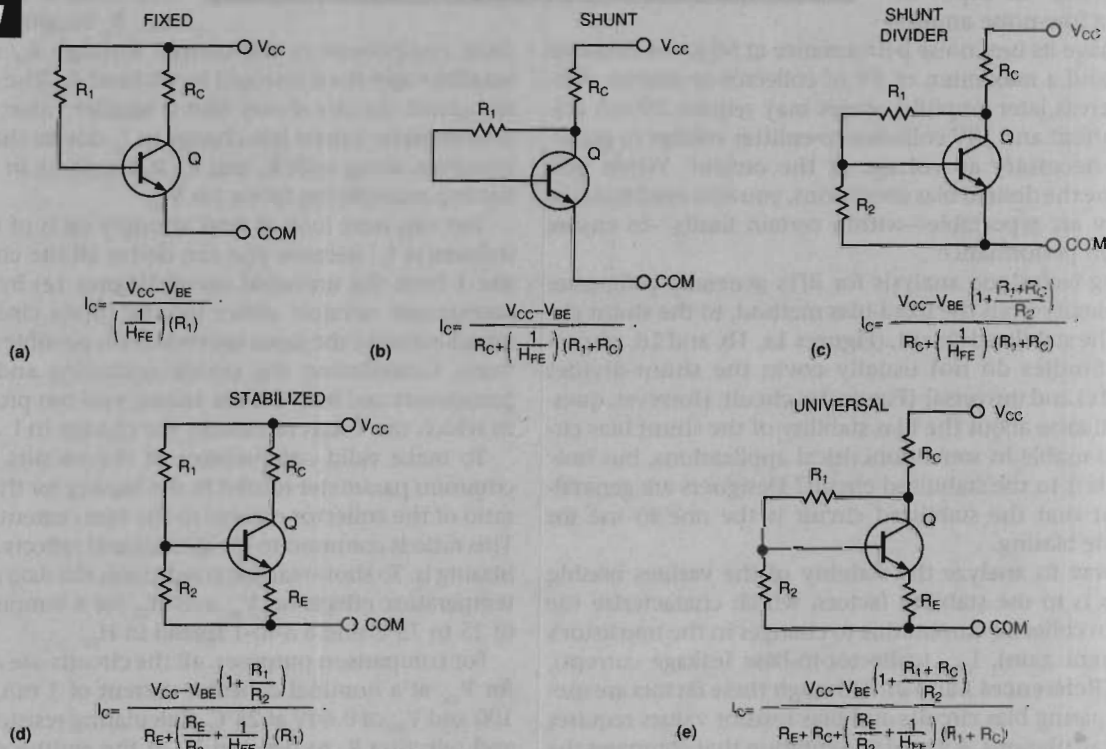
The horizontal axis is the ratio of the collector current, I_C , to the current in resistor R_1 . This bias ratio applies to all the circuits and indicates how much current is in the base-biasing network compared with the collector current. Thus, a ratio of 1 indicates a stiff bias circuit, with as much current in R_1 of the bias network as in the collector, whereas a ratio of 50 indicates that the collector current is 50 times the current in R_1 of the bias network. Because some of the results are unexpected, they give renewed consideration to some of the bias circuits previously ignored.

The universal-bias method is obviously the best of the group. The price you pay for its dc stability is the reduction in ac input resistance due to the negative feedback on R_1 , a sort of Miller effect on resistors. R_1 reduces by a factor of the voltage gain plus 1. This feedback may improve distortion and bandwidth as well as reduce the output impedance at the collector. If you don't want these ac effects of feedback, you can eliminate them by splitting R_1 into two parts and bypassing the center to ground (Figure 3). You can improve performance of this circuit at any bias ratio by increasing the voltage drop across R_E , increasing the voltage drop across the collector resistor, or both.

The stabilized circuit has good stability to bias ratios as high as about 12. Above this ratio, its stability rapidly decreases. The stabilized circuit relies on the voltage changes fed back by the emitter current through R_E , compared with the voltage, V_B , at the base. When the bias ratio becomes less stiff, changes in base current flowing through R_1 due to changes in H_{FE} cause significant variations in V_B . These variations result in changes in I_E and I_C . As with the universal circuit, you can improve performance of the stabilized circuit at any bias ratio by increasing the voltage drop across R_E . Keep in mind that these results are for a nominal H_{FE} range of 50 to 150 plus temperature effects. Lower minimum values of H_{FE} require stiffer bias ratios for the same performance.

The superior performance of the shunt-divider circuit at

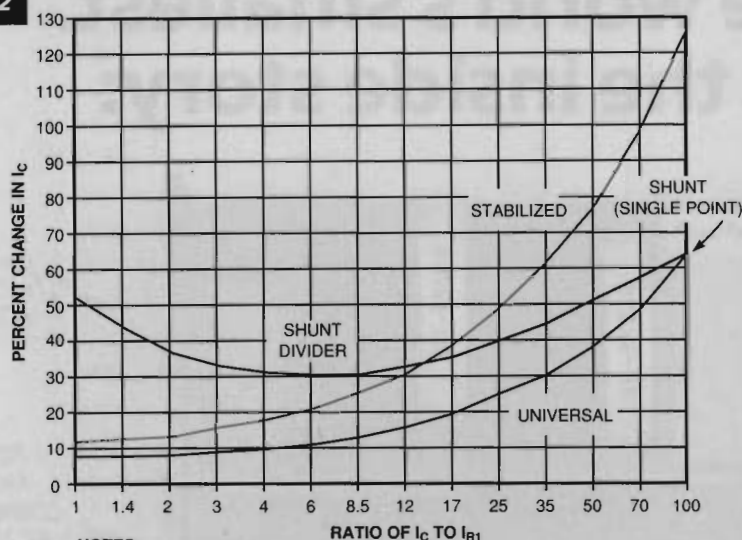
FIGURE 1



The five basic bias circuits are fixed (a), shunt (b), shunt-divider (c), stabilized (d), and universal (e), each shown with the corresponding circuit equations.

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FIGURE 2



You can compare the performance of the BJT bias circuit by graphing the change in collector current vs the ratio of the collector current to the current in R_1 .

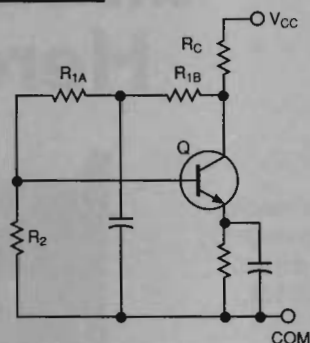
bias ratios greater than 12, compared with that of the stabilized circuit, is a surprise. When the shunt-divider circuit's bias is stiff, V_C is strongly influenced by the ratio of R_1 to R_2 times V_{BE} . As V_{BE} changes because of temperature, V_C and, thus, I_C , change approximately as the ratio of R_1 to R_2 times V_{BE} changes.

Because I_C plays the major role in determining V_C , I_C experiences wide variations for these stiff biasing ratios. As the ratio becomes less stiff, the changes in V_{BE} with temperature, multiplied by the voltage-divider action, become less dominant, and performance improves until, at the ratio of about 12, the shunt divider's stability starts to surpass that of the stabilized circuit. You can account for this performance by the negative feedback from the collector resistor through R_1 . Because the collector resistor is usually much larger than the emitter resistor of the stabilized circuit, the stability of the universal circuit holds up better for less stiff bias ratios.

Because the shunt-divider circuit is more stable than the shunt circuit, consider the divider circuit for applications that need less stability than the stabilized or universal circuits offer. Because it saves the cost of the emitter-bypass capacitor necessary in the universal and stabilized circuits, the shunt divider can be more cost-effective. Negative feedback through R_1 in the shunt-divider circuit reduces the input resistance and may improve distortion and bandwidth, as well as reduce the output impedance in the same manner as in the universal circuit. Again, you can negate these effects with a bypass capacitor in the center of R_1 . This bypass capacitor is typically much smaller than the emitter-bypass capacitor for the stabilized circuit.

Because the bias current for the shunt-bias circuit consists of only the base current, it has only one ratio of I_C to I_{R1} ,

FIGURE 3



To eliminate the ac effects of feedback, split R_1 , and bypass the center to ground.

namely H_{FE} , and is plotted as a single point. As the bias ratio for the universal and shunt-divider circuits increases, the value of R_2 increases until it becomes infinite at an H_{FE} of 100.

Under these conditions, the circuits' bias ratios converge with the shunt-circuit ratio.

Figure 2 leads you to several general conclusions. The universal circuit has the best stability over the widest range of bias ratios. The stabilized circuit has good stability for stiff bias ratios, but you should take care if biasing ratios exceed 12. And, finally, the shunt-divider circuit is a significant improvement over the shunt circuit and is better than the stabilized circuit for large bias ratios. **EDN**

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Author's biography



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